# The Glasgow 10m Interferometer

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LIGO-G1000925

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# OVERVIEW

- **A bit of History + Overview of the facility**

- **Experimental Results**
  - Control of coupled cavities
  - Direct thermal noise measurement
  - Diffractive cavity (2nd Littrow)
  - Optical Springs with a 100g mirror

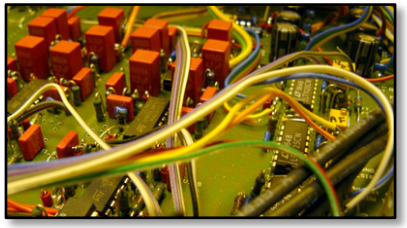
- **Planed Experiments**
  - Waveguide in a suspended cavity
  - Interferometry with Laguerre Gauss modes
  - Optical Rigidity: *e.g. Optical Bar configuration, Double Optical Spring, Quantum Control, Negative Inertia …*

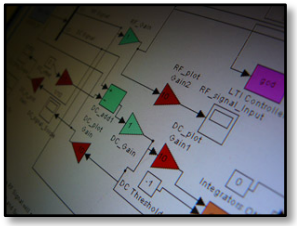
# A bit of History …

- **The Glasgow 10m Prototype was first set up in 1978.**
- **Plenty of pioneering work:**
  - 1st ever coincidence run of two interferometers (together with Garching 30m)
  - Multiple-stage suspensions
  - etc …
- **Complete refurbishment of lab after 2000 …**
- **Since then we have the NEW Glasgow 10m Interferometer.**

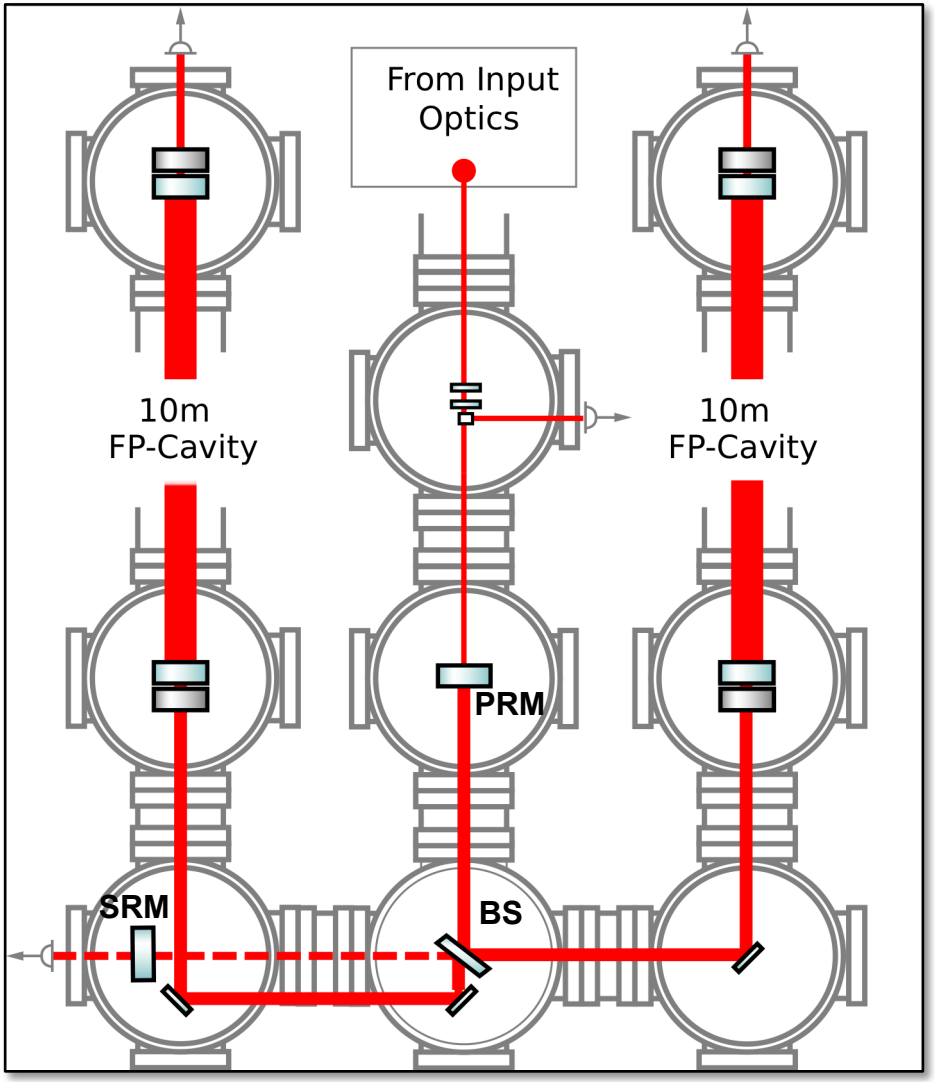

# Overview of the facility (1)

- **GEO-like Infrastructure:**
  - Similar vacuum systems
  - Triple Stage GEO-suspensions
  - Same local control
- **Class 100 cleanroom + additional cleanroom tent around every tank.**
- **Analog and Digital Control**
  - dSPACE + aLIGO CDS



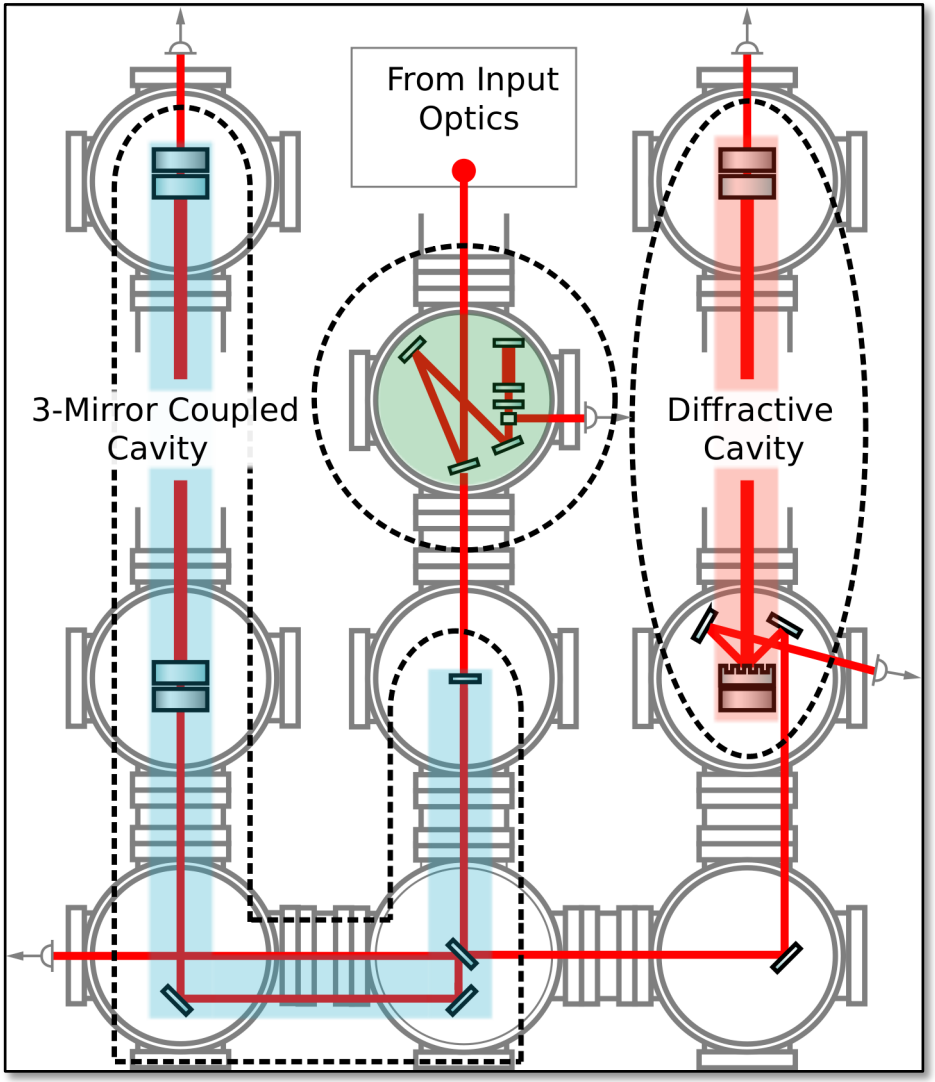


- **Originally planned to accom-modate a full aLIGO configuration (FP-MI with Dual-Recycling)**



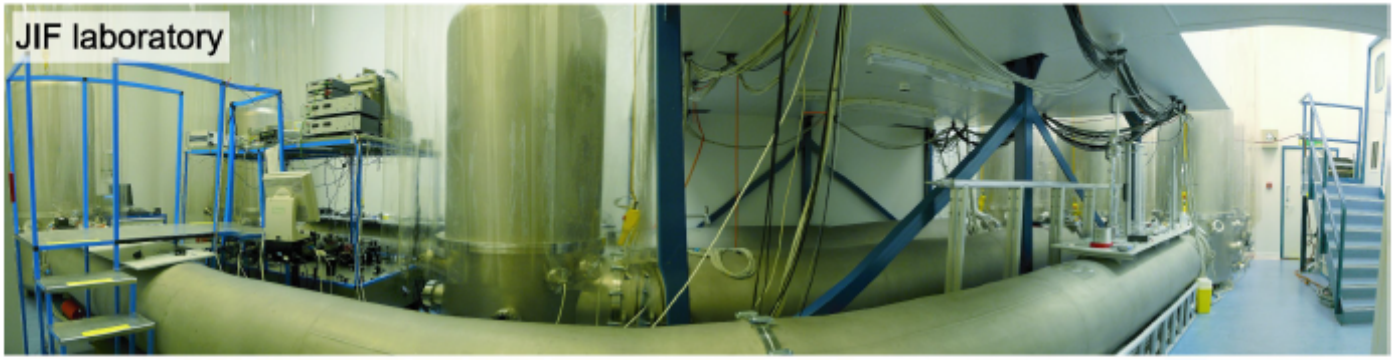
# Overview of the facility (2)

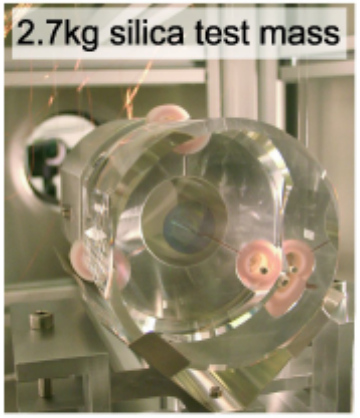
- **Maximise the potential of the Glasgow 10m by carrying out several strands of experiments in parallel:**
- **Direct measurement of thermal noise**
- **3-mirror coupled cavity systems:**
  - Control strategies
  - Radiation pressure experiments
  - Frequency reference for TN experiment
- **Diffractive interferometry**
  - Grating as cavity incoupler
  - Waveguide mirror

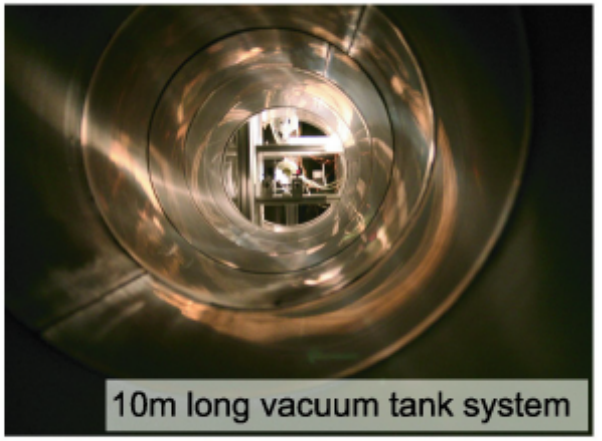


# The Glasgow 10m Prototype Interferometer

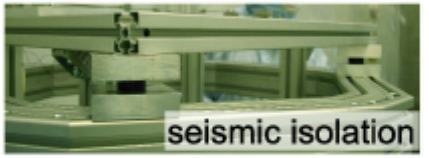
- Ideal test bed for advanced interferometry concepts.
- Fast turn around for rapid, small-scale tests
- Timely validation of various innovative technologies
- Excellent training for students and Postdocs

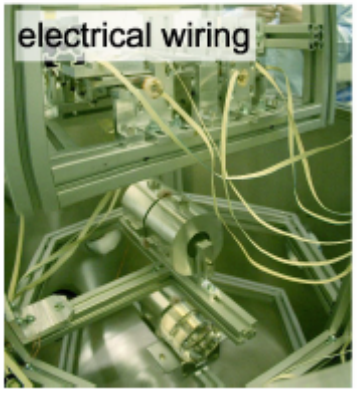




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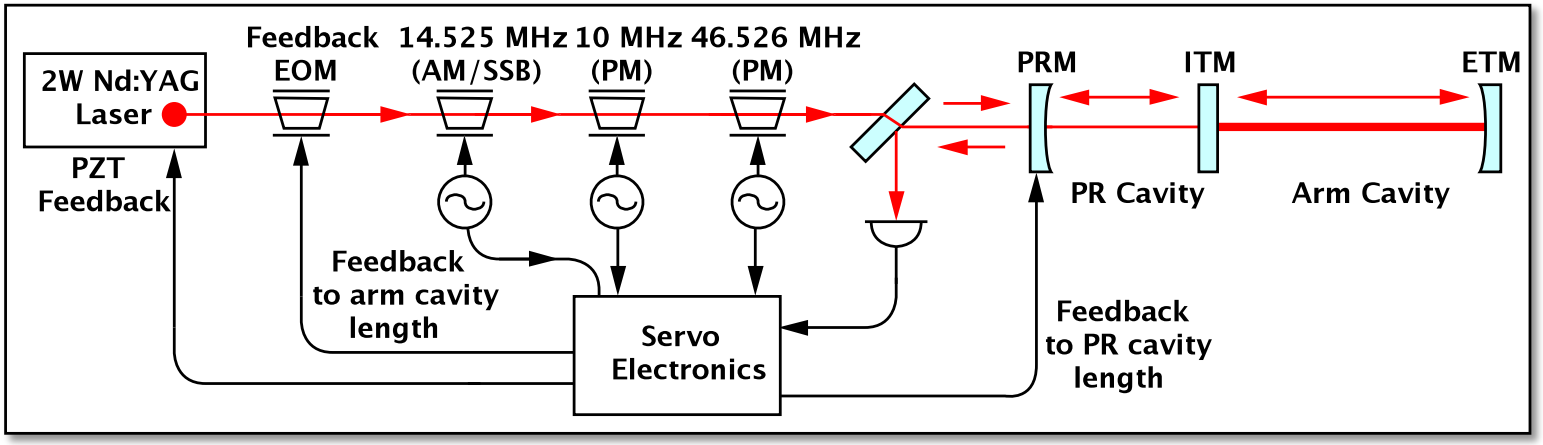
# Control of coupled cavity systems

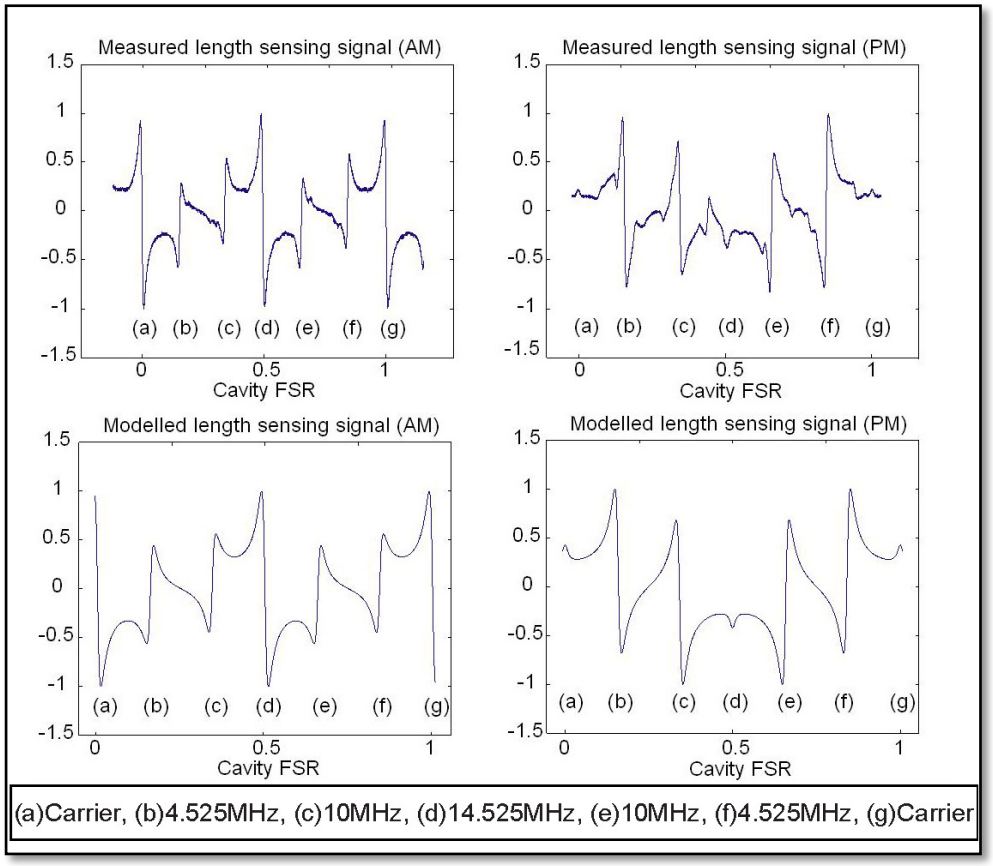
- **Aim: Develop Control scheme for a linear 3-mirror cavity:**
  - Providing independent error-signals for the 2 degrees of freedom
  - Allowing us to easily detune one of the cavities, without disturbing the other (needed for optical spring experiments).




- **Method makes use of 3 RF modulation frequencies:**
  - PM sidebands @ 18MHz used to derive AC length-sensing signal.
  - PM sidebands @ 10MHz, and AM sidebands @ 14.525MHz used to derive recycling cavity length-sensing signal.

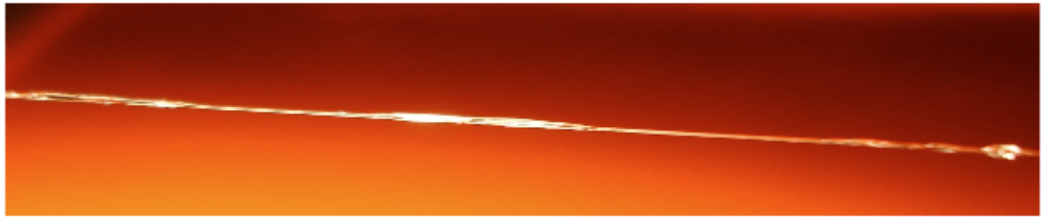
# Control of coupled cavity systems

- **Concept works very nicely.**
- **More details on the experimental results can be found in:**
  - S.Huttner et al: ”Novel sensing and control schemes for a three-mirror coupled cavity”. *CQG,* 2007*, 24*, 3825
  - B. Barr et al: “Optical modulation techniques for length sensing and control of optical cavities” *Appl. Opt., OSA,* 2007*, 46*
  - S. Huttner et al: “Techniques in the optimization of length sensing and control systems for a three-mirror coupled cavity”, *CQG,* 2008*, 25*, 235003
- **Concept can also be useful locking Khalili cavities (as ETM), for instance in AEI-10m sub-SQL experiment …**

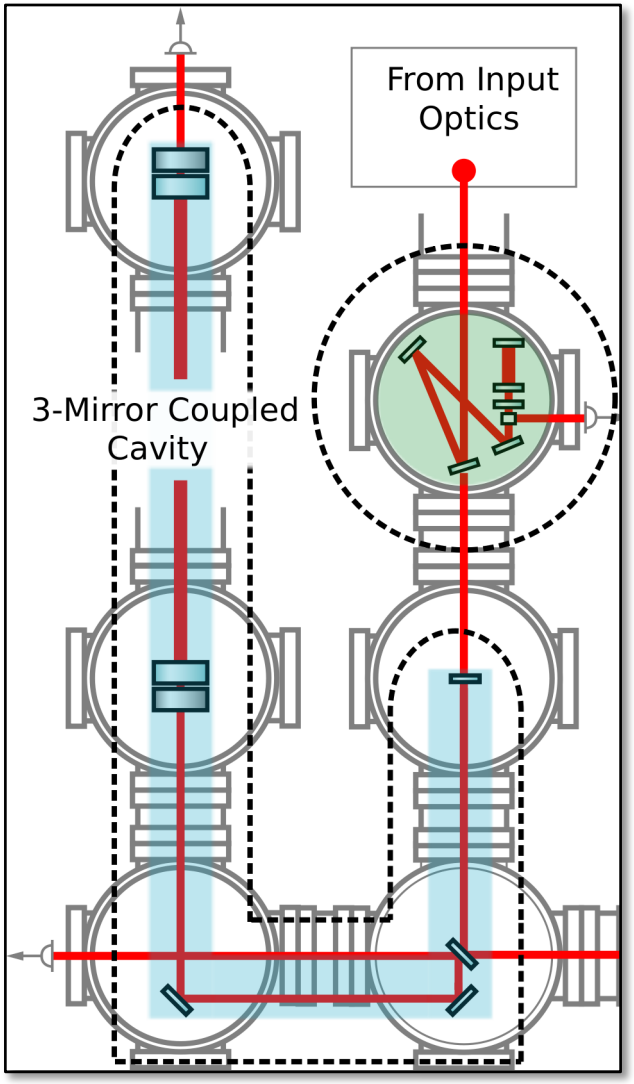


# Direct Thermal Noise measurement

- **Aim: To directly measure coating Brownian noise at frequencies around 100 to 200Hz.**
- **Short (10cm) high-finesse (about 5000) measurement cavity.**
- **10m cavity serves as frequency reference.**
- **Very sophisticated test mass suspensions (3 stages, last stage is monolithic)**
- **Target sensitivity: about $3 \times 10^{-18}$m/sqrt(Hz)**

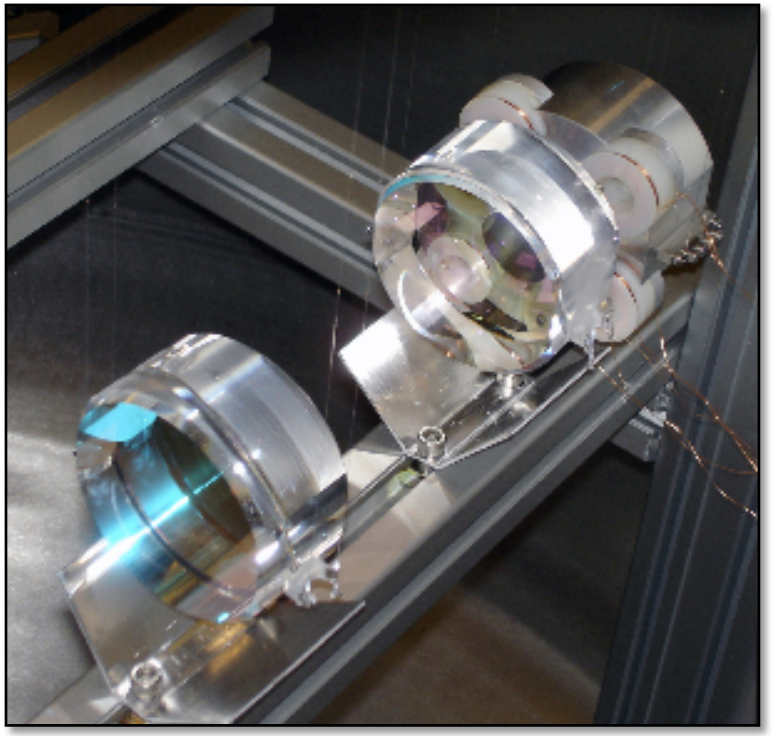


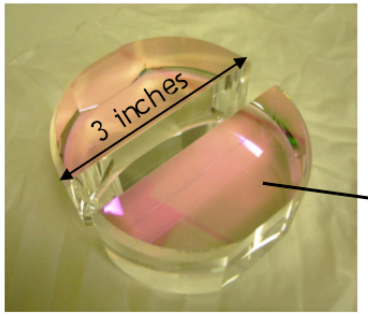
More details on the thermal noise experiment: J.Taylor, PhD-thesis



# Direct Thermal Noise measurement

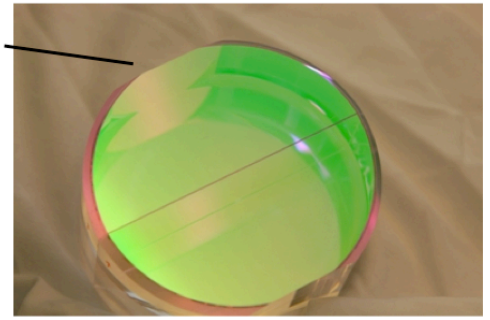
- **Current status: Haven't reached target sensitivity => More noise-hunting is needed. Potential noise candidates:**
  - Electronic noise in frequency-stabilisation loop
  - Cross-coupling between 10cm and 10m cavities
- **What could we do with the experiment once we reached target sensitivity?**
  - Measurement of coatings at the frequencies within the detection band of the large GWDs.
  - Measurement of thermal noise of a hydroxid bond.
  - Other fun stuff such as LG-modes or Waveguide coatings….





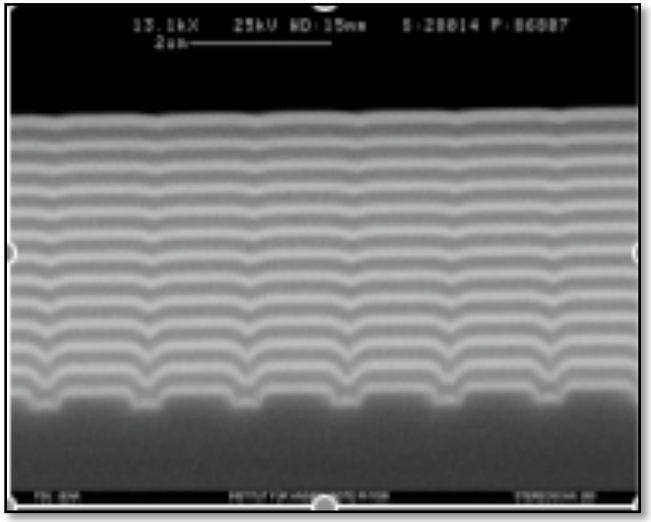

Parts to form composite mass

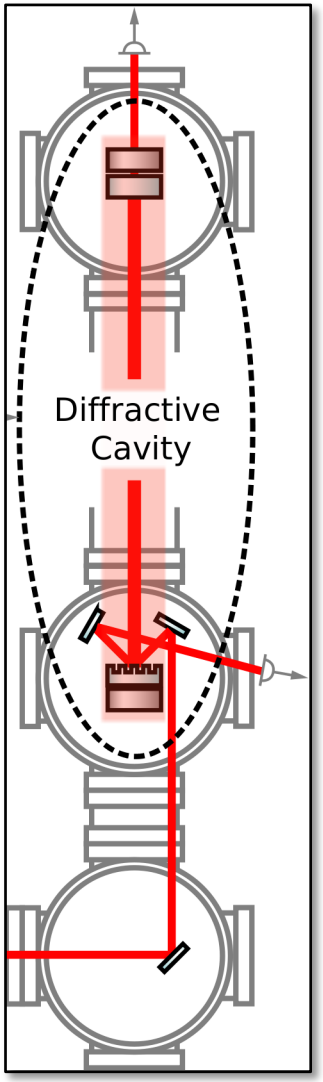
Silicate bonded composite mass



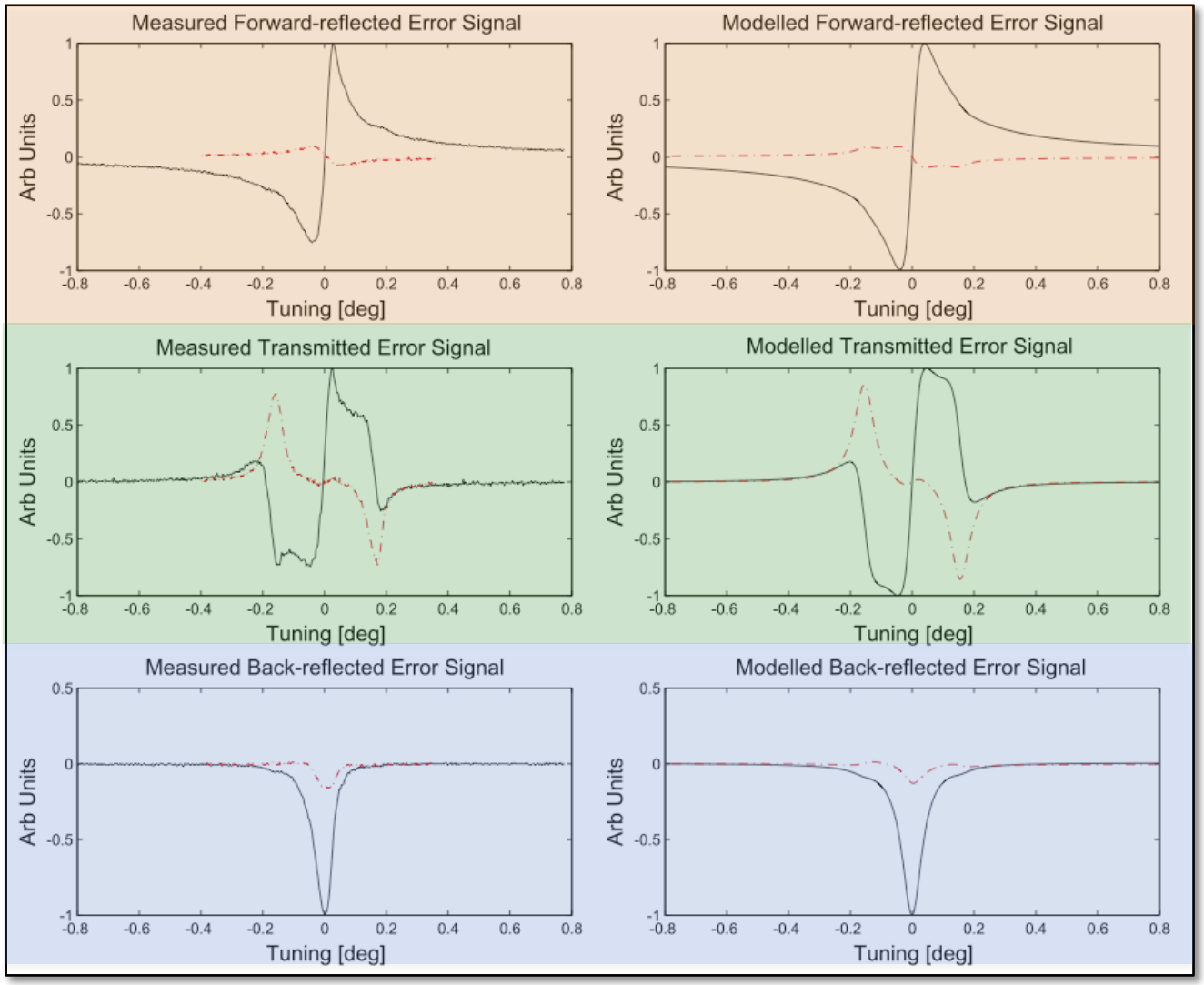
# Diffractive coupled cavity

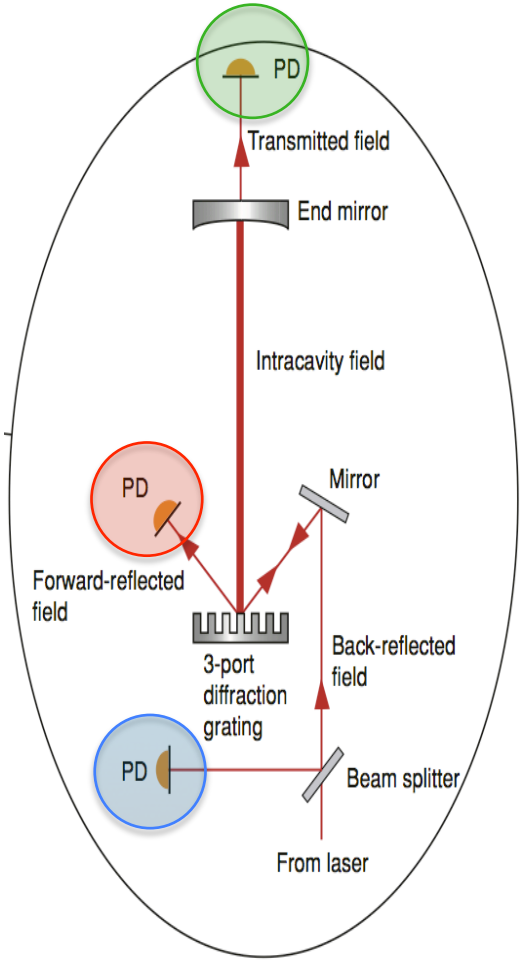
- **Motivation: Gratings can be used to replace transmissive optics => can decrease thermal problems and some thermal noise contributions.**
- **First demonstration of a suspended cavity using a 3-port grating as cavity incoupler (2nd order Littrow).**
- **Collaboration with Universities of Hannover, Jena and Birmingham.**
- **Using an grating etched into a fused silica substrate then over-coated with multi-layers of $Ta_2O_5$ and $SiO_2$.**
- **Achieved Cavity Finesse of about 1100.**
- **Detailed characterisation of signal ports completed.**





# Diffractive coupled cavity



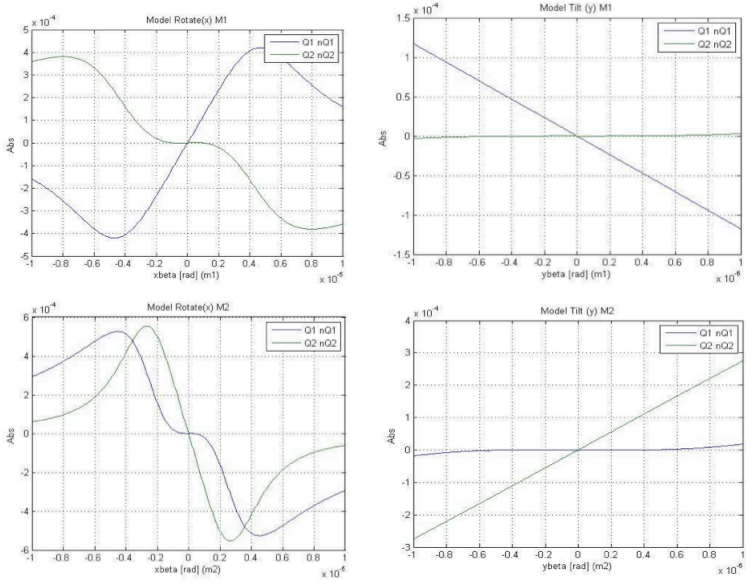

For details please see:

- M.Edgar et al., *Opt. Lett.*, 2009, *34*, 3184-3186
- M.Edgar et al. *CQG*, 2010, 27 084029

# Diffractive coupled cavity

- **Two more examples of interesting investigations:**

## Alignment sensing



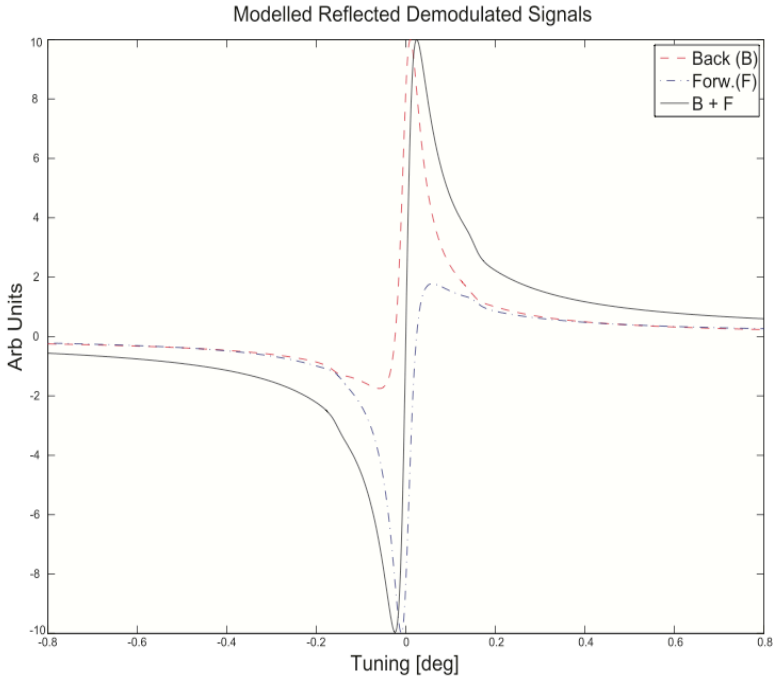

**Simulated Error Signals**

| | PD1 (Scaled) | PD2 (Scaled) |
|---|---|---|
| M1D | 0.0447 | 0.0000 |
| M1E | 0.0000 | 0.0572 |

**Measured Control Matrix**

More details:
- K. Arndt, Masterthesis
- B.Barr et al., in preparation

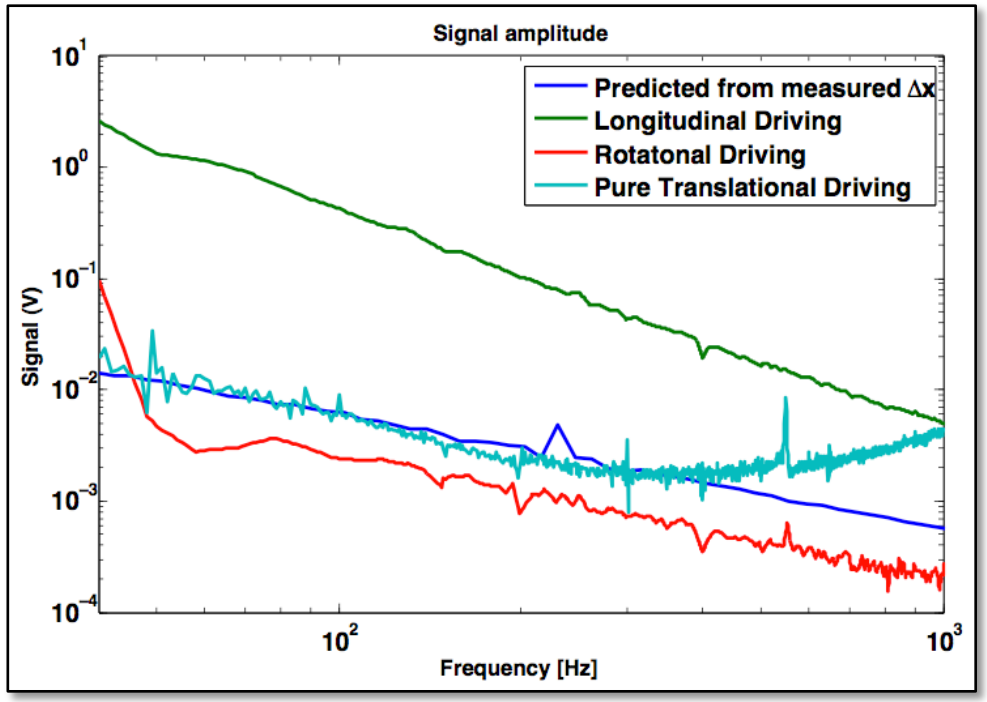
## Signal Mixtures

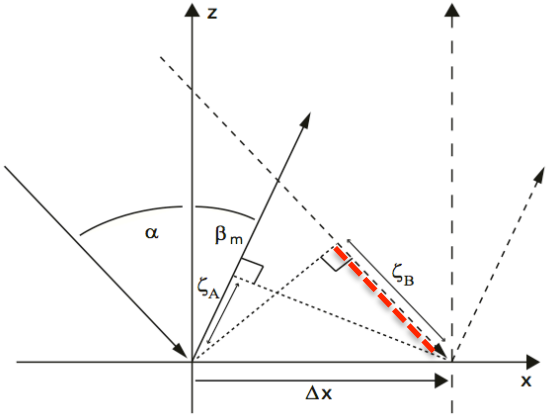


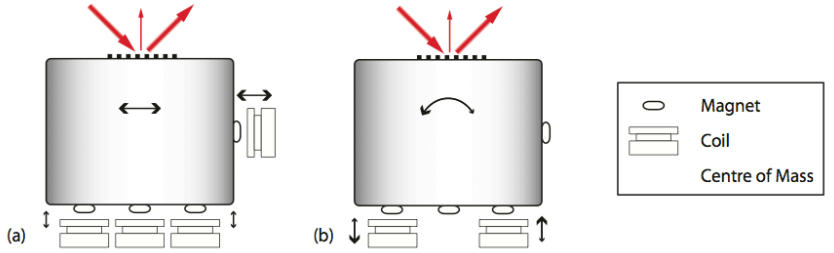

**Recovery of symmetric PDH signal by using the sum of the forward and back-reflected photodiode signals**

# Diffractive coupled cavity

- **Experimental confirmation of phase noise from side-motion of the grating.**
- **Prediction that in contrast to a normal mirror, sidemotion of a grating, introduces additional phase noise.** (Freise et al, *New J Phys*, 2007, 9, 433-+)



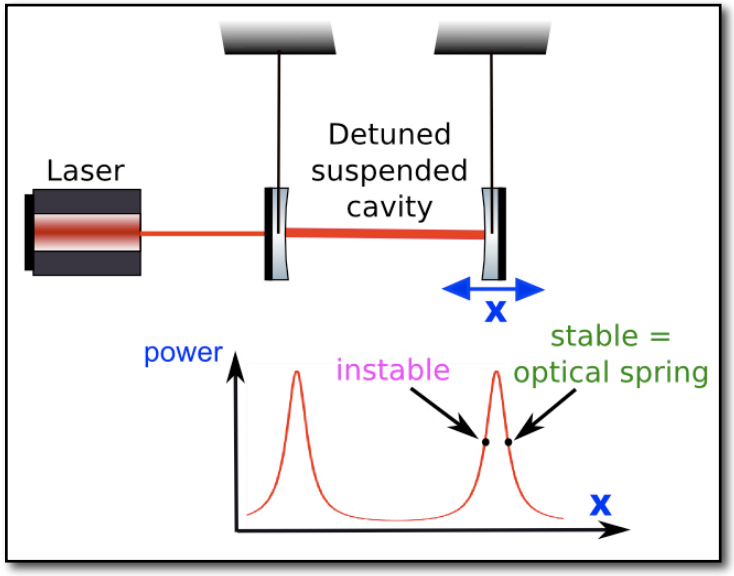



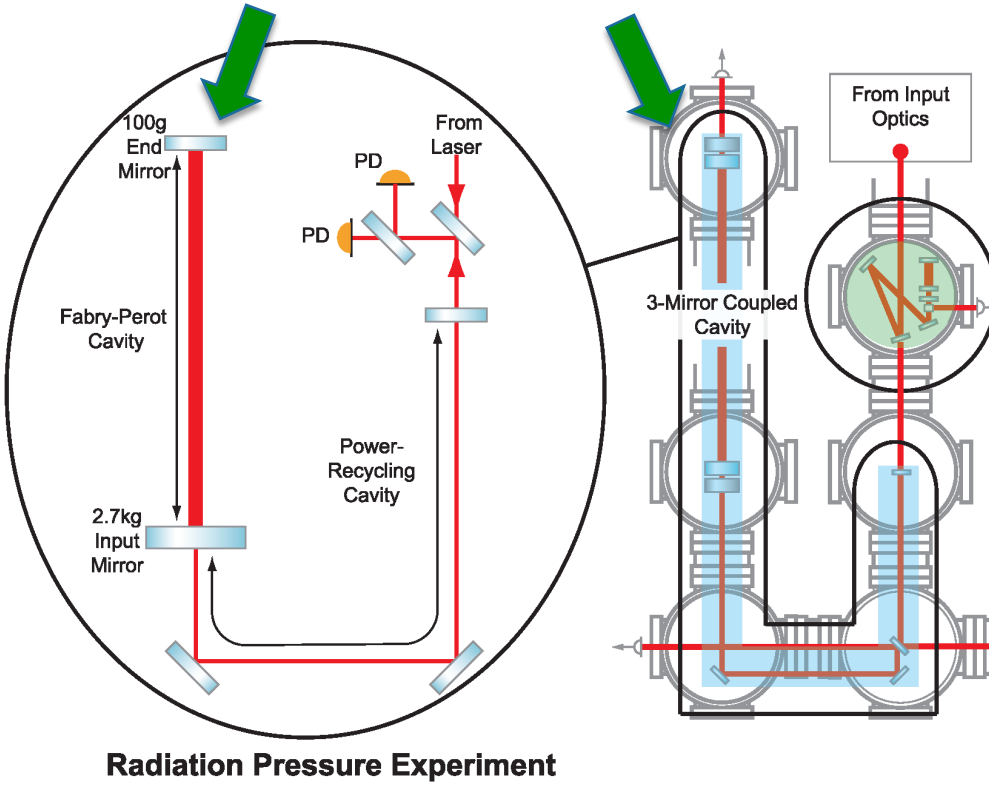




More details: B.Barr et al, "Translational, rotational and vibrational coupling into phase in diffractively-coupled optical cavities", soon in LSC-review …

# Optical spring with a 100g mirror

- **Aim: Measure optical spring of a 100g mirror.**
- **Motivation: precursor for other optical rigidity experiments (also at AEI-10m sub-SQL-interferometer).**
- **We replaced the endmirror (2.7kg) of the 3-mirror cavity by a very light mirror (100g) in order to enhance the radiation pressure effects.**

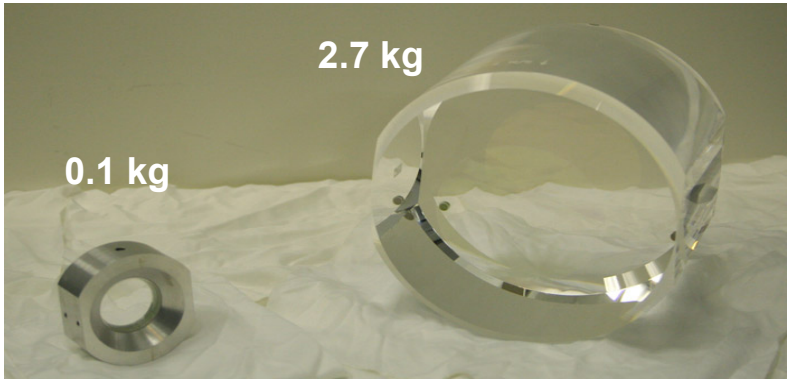


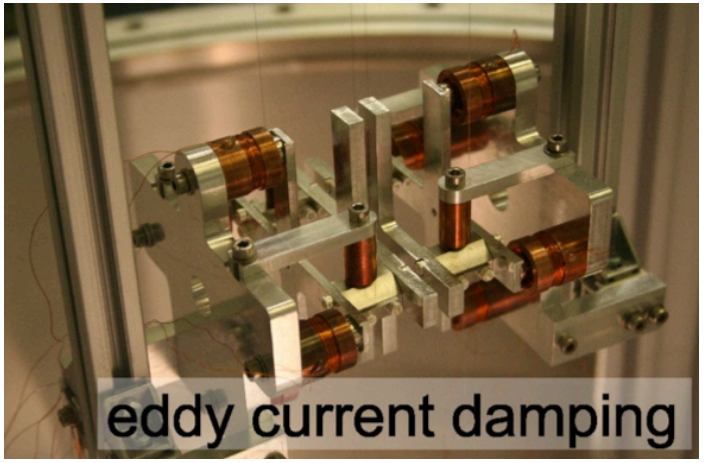



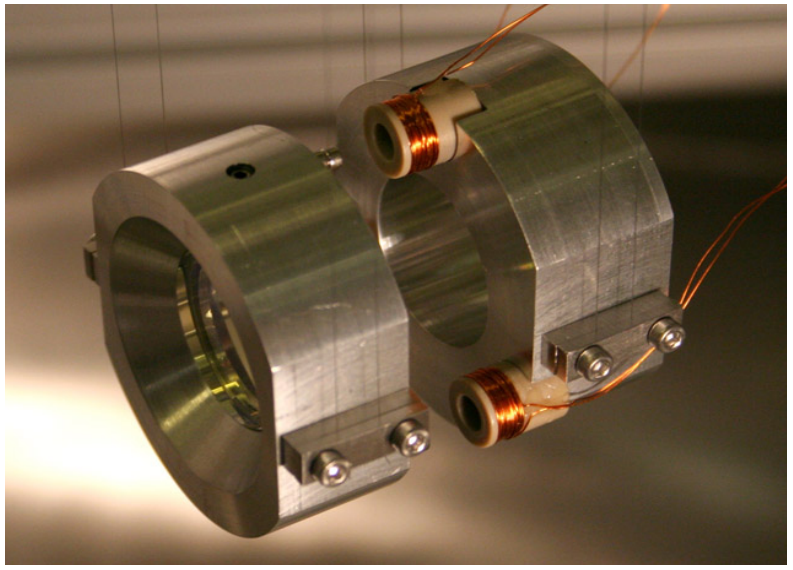

**Radiation Pressure Experiment**

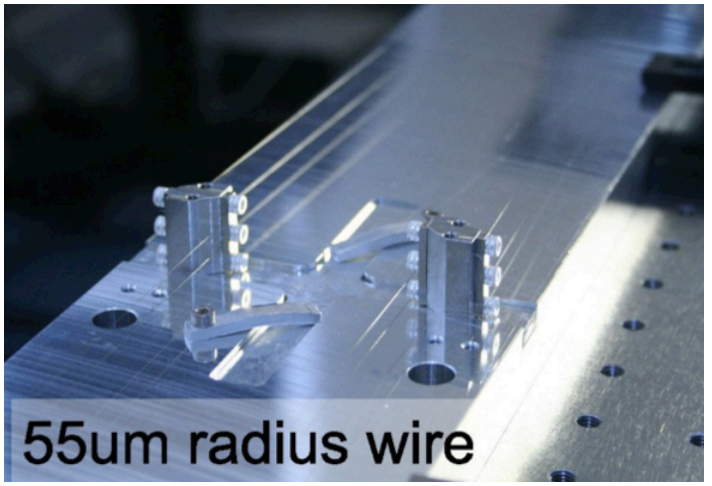
# Optical spring with a 100g mirror

- **Triple-stage suspension + reaction chain.**
- **Much of this design serves as reference for the suspension for the AEI-10m**






# Optical spring with a 100g mirror

- **Some preliminary results ….**

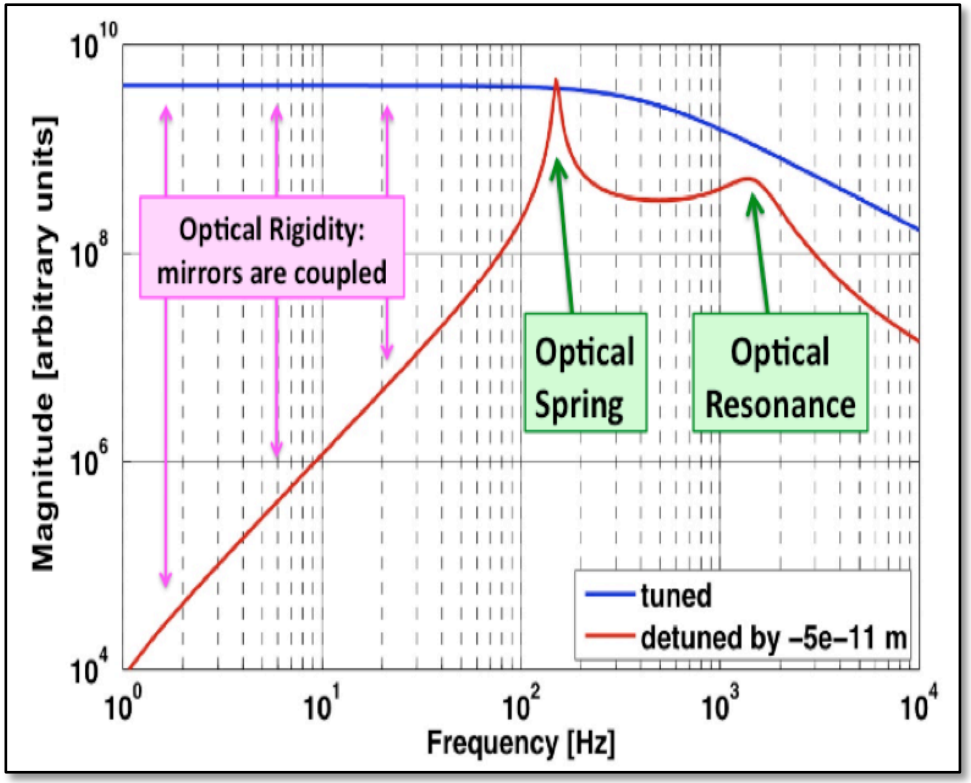
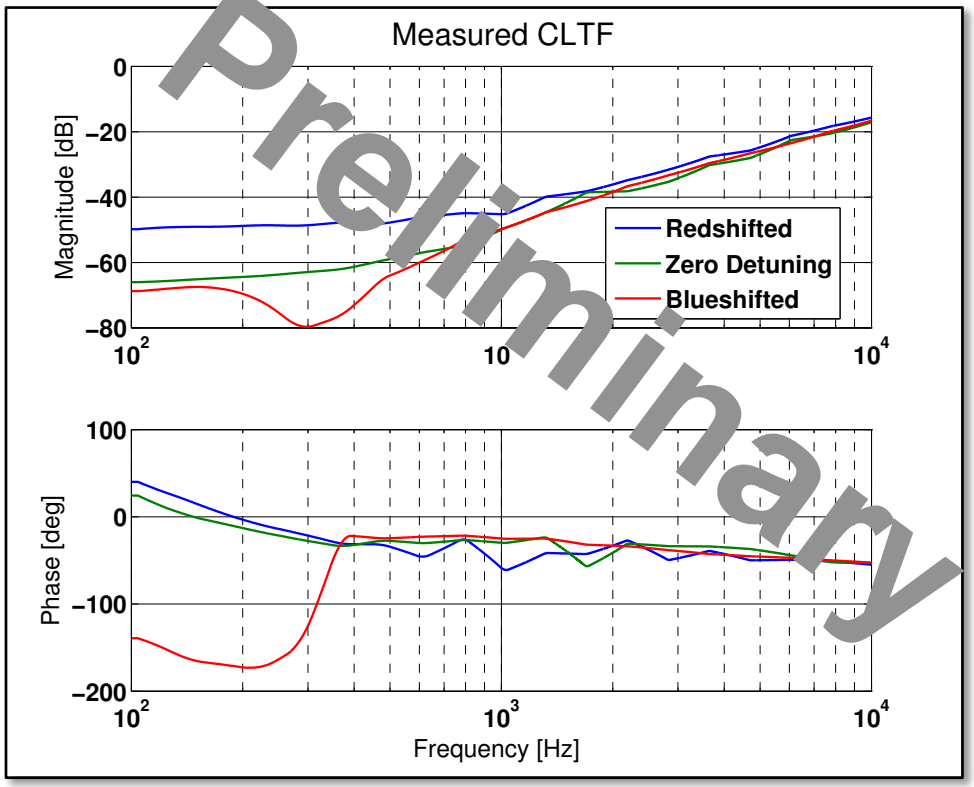



**Illustration of OLTF**




**Measured Data (CLTF)**

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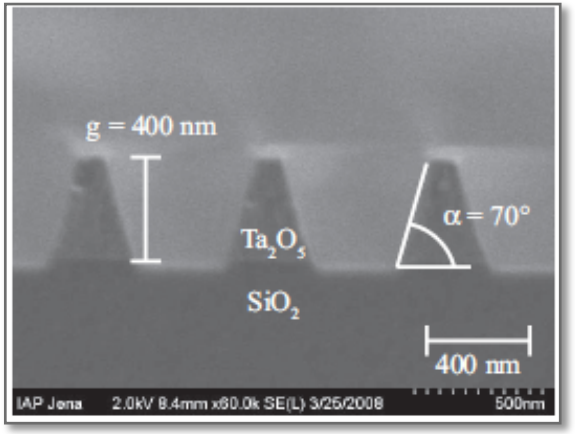
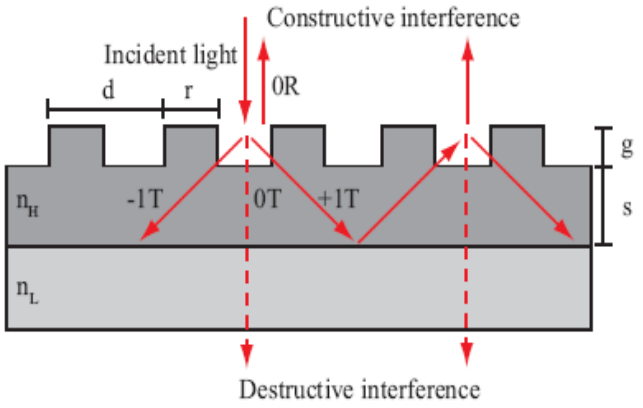
  - Optical Rigidity: *e.g. Optical Bar configuration, Double Optical Spring, Quantum Control, Negative Inertia …*

# Waveguide coating

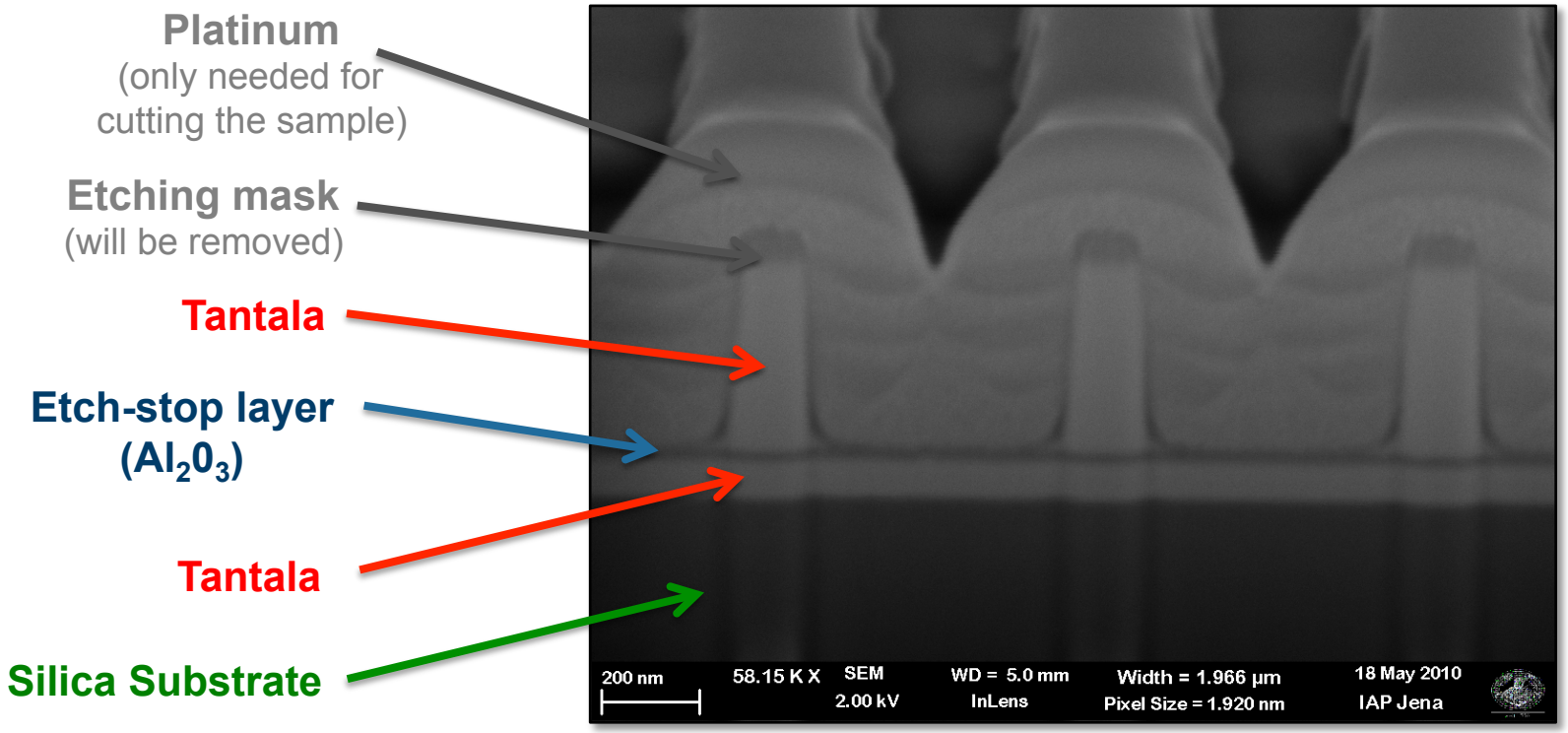
- **Motivation: Waveguide coatings might provide very low thermal noise.**
  - A.Bunkowski et al: *CQG,* **2006***, 23*, 7297-7303
  - F.Brückner et al: *Opt. Lett., OSA,* **2008***, 33*, 264-266
  - F.Brückner et al: *Optics Express,* **2008***, 17*, 163-
- **Aim: Demonstrate suspended cavity with waveguide mirror**
- **Collaboration with AEI-Hannover and Jena University. Main actors: D.Friedrich (Hannover) and F.Brueckner (Jena).**
- **Jena produced a batch of waveguide mirrors (1064nm) for the Glasgow 10m Prototype.**
- **Reflectivity of 99.5%** *(preliminary result)*
- **Installation will start in 10 days.**

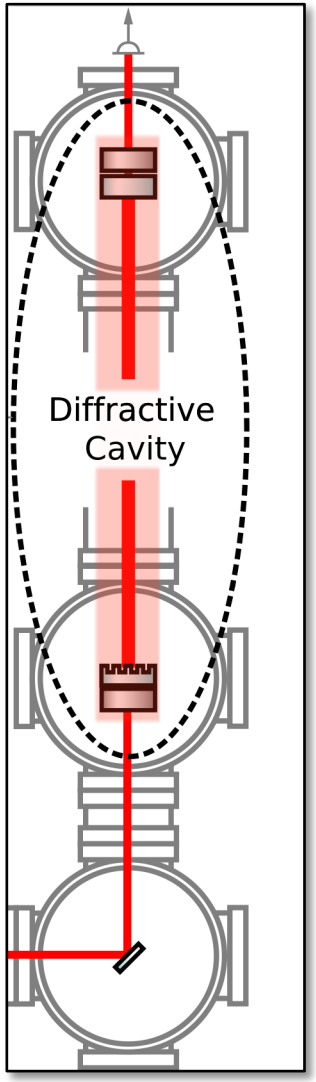


# Waveguide coating

- **Install the waveguide mirrors as ITM. Planned experiments:**
  - Investigate control signals
  - Demonstrate the absence of sidemotion noise
  - Investigate homogeneity and and scattered light

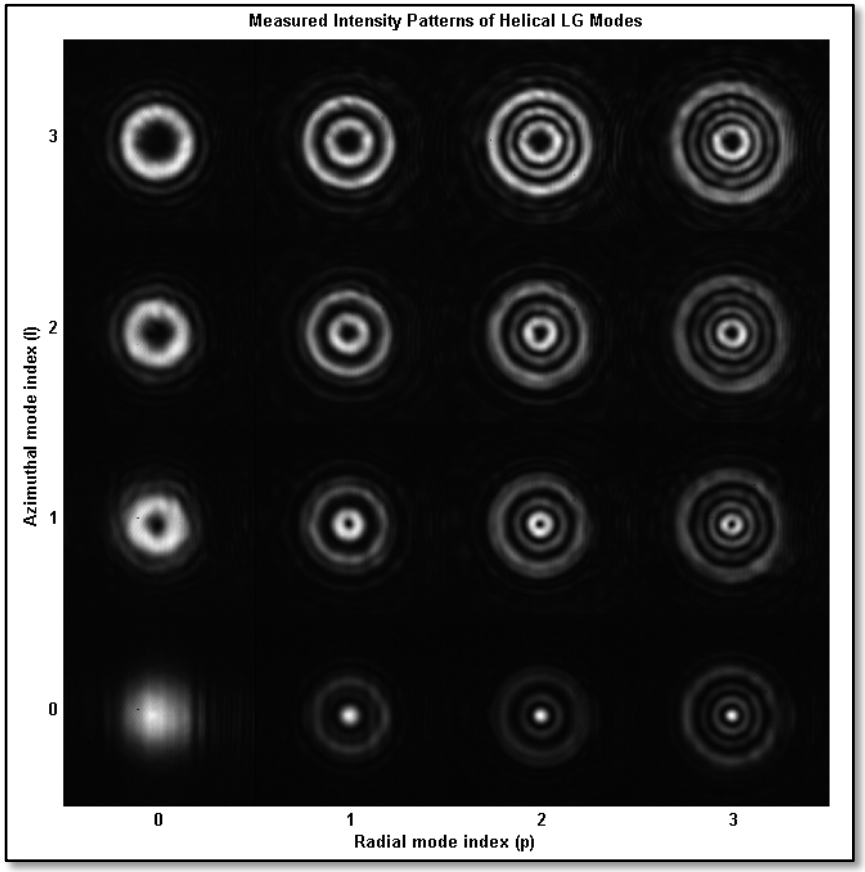


# LG-modes

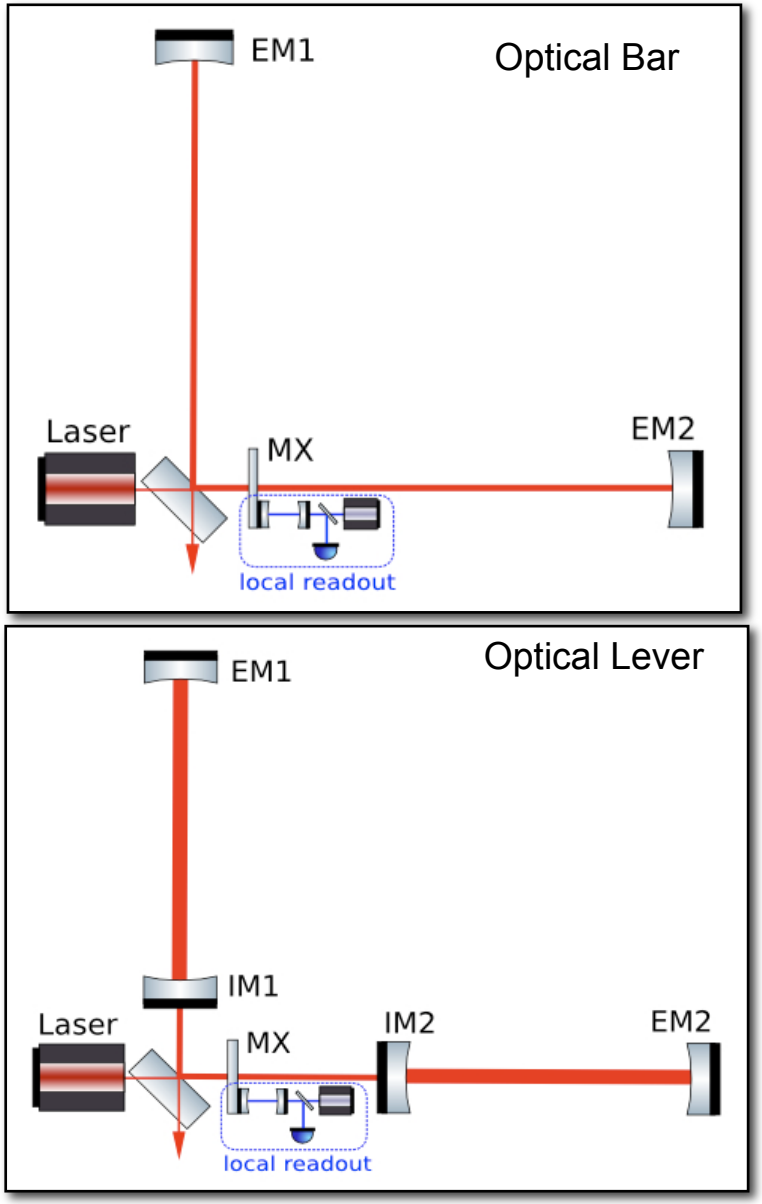
- **Motivation: LG modes can provide a reduction in thermal noise.**
- **Simulations and experiment of LG-interferometry seem promissing.**
  - S.Chelkowski et al: ”Prospects of higher-order Laguerre-Gauss modes in future gravitational wave detectors”, *PRD,* **2009**, *79*, 122002
  - P.Fulda et al: “Experimental demonstration of higher-order Laguerre-Gauss mode interferometry”, *PRD,* **2010**, *82*, 012002
- **Time for testing in an environment similar to a GW detector.**
- **Collaboration with University of Birmingham.**
- **Main aims:**
  - **Study of control signals**
  - **Investigate effects from mode-degeneracy**

**Examples of higher order LG modes produced with a spatial phase modulator**



# Optical rigidity

- **Will continue on investigations on interferometer concepts based on optical rigidity.**
- **One potential experiment would be to go back to a heavy ETM and install very light ITM + a local readout for the ITM. => Close to an optical bar / optical lever configuration.**
- **Other routes currently considered and theoretically investigated are:**
  - **Double optical springs**
  - **Negative inertia**
- **Collaboration with Moscow (S.Vyatchanin and A.Rakhubovsky)**



# Summary

- The Glasgow 10m Prototype is a fully operational Multi-Experiment facility.
- Strong link with AEI-10m sub-SQL interferometer.
- Lots of interesting interferometry concepts under investigation.
- Lively exchange of PhD-students. Everybody is welcome to join …

…END